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Fuzzy Takagi-Sugeno Method in Microcontroller based Water Tank System

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ABSTRACT

This paper presents the performance of Fuzzy logic controller in maintain level of water in water tank system. The mathematical modelling was developed to get the initial idea of the system performance. Later, the prototype of water tank system was constructed and tested to get the real time results. The Takagi-Sugeno “on” and “off” interference technique method was implemented due to the control limitation of the pump motor that being used in the experimental setup. The fuzzy logic controller was realized by embedded the algorithm in microcontroller of the water tank system. The experimental results show acceptable level of water within the range of 18cm to 20.5cm and settling time 59 seconds with 20cm set point.

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1. INTRODUCTION

Managing the water reservoir is important in many sectors such as in agriculture, chemical and liquid industries, fishery and etc. One prominent aspect need to be looked into is the level of water in tank used in the manufacturing process system. The focus will be in maintaining the water level to meet the daily requirements.

In maintaining the level of water tank, a lot of study has been done to automatically control the level of water tank system. The most accepted water level controller is PID controller that widely use in both laboratory and industrial sector. This is due to the controller ability to fit majority of water tank system with its simplicity and generality despite of size, tank construction, monitoring system and location at the plant. However, the difficulty in tuning the PID parameters and the moderate performance of the level control requires extension method in optimizing the performance [1].

XiaomingZao [2] introduced RBF network in PID controller to reduce the effect of uncertain initial parameter value of the water tank system. Yan Zhao [3] choose Fuzzy-PID to improve the PID controller performance whereas Sharma et al [1] using GA and PSO in tuning the PID gain for a simple water tank system. Despite of good performance shown, additional method may increase the computational burden and no longer hold the simplicity aspect that supposed to be held by the PID method which leads to the discovery of other control method.

There is a discussion on implementation of stand alone intelligence control in water tank system. It’s features that adapt human decision making capability provide faster response to the system [3]-[5].

Furthermore, the intelligent control method does not require extensive mathematical description of the controller [6]. Xu et at [7] using the neural network to solve delay problem faced by PID controller and come out with reduce overshoot response. Cervantes et al [8] study the performance of Type-1 and Type-2 Fuzzy system design using genetic algorithm in three water tank level and conclude with improvement performance in the proposed method compared to the initial ones. Deepa et al [9] explain the comparison between PID and fuzzy logic controller in water tank system. The study shows that fuzzy logic ontroller gives better overshoot and settling time than PID controller. The same results show by Xinli et al [10] with the same study but diffrent approach in fuzzy membership function. All of the study gives an insight of good performance achived by intelligent controller which later left with the question on how far the approach fit the practical aspect of real water tank system.

Wu He et al [11] study real time implementation of Fuzzy-PID algorithm using reliable OLE for process control technology with real water tank equipment. The results show less percent overshoot but author couldn’t hold the value of settling time. Vojtesek et al [12] using the Real Time Toolbox in MATLAB environment for the real model of water tank and come out with nearly similar with Wu Hee [11]. Aphiratsakunet al [13] implementing PLC as the controller for the water level system and integrate with PID controller that being realize with amplifier gives only 7% error at the output. Attempt in using microcontroller done by Pratame et al [14] which implement the PID controller with anti wind up for water tank level that come out with nearly to zero percent overshoot and more than 100 seconds for rise time and settling time. The same overshoot performance show in realization of fuzzy logic in [15] but no detail discussion on the time response.

Our proposed method adhere the adaptive concept in water level system that tailored the desired output to adapt with changing of water level. The input parameter of the system will be defined in linguistic manner of Fuzzy Logic in minimizing the output error. The control action of open and close valve was interpreted in a list of the rule based. Since common AC water pump has only on-off control mechanism, it is the best to implement the Takagi-Sugeno interference technique. This method will minimize the cost of finding another water pump while adding the simplicity onto fuzzy controller itself. In order show the performance of the proposed method, real time response of microcontroller based of water tank system will be explained later throughout this paper.

2. RESEARCH METHOD

2.1. Mathematical modelling of water tank system

The mathematical modelling of water tank was referred to [14]. Total flow rate of a tank system, QT equivalent to the difference of input flow rate, QIN and output flow rate, QOUT. This will affect the volume inside the water tank. Since the cross-sectional area of the water tank is constant, the most obvious changes will be on the height of water inside the tank. Two water tank system of the schematic diagram as shown in Figure 1.

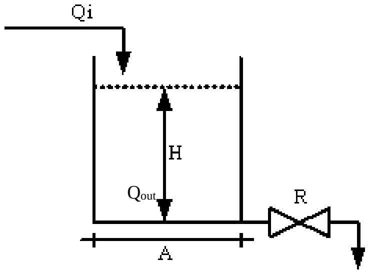


Figure 1. The schematic diagram of two water tank system

For mathematical modelling purpose, we are going to illustrate the general transfer function, of one water tank system as shown in equations (1) and (2).

$$Q_T = Q_{IN} - Q_{OUT} \tag{1}$$

$$Q_T = Q_i - Q_{Out} \tag{2}$$

If the A is the cross-sectional area of the tank and the H is the height of the water in the tank, R is the valve resistance of the equations (3-5) can be written as

$$A\frac{dh}{dt} = Q_i - Q_{out} \tag{3}$$

$$Q_{out} = \frac{1}{R}\,H \tag{4}$$

Substituting (3) into (4) to eliminate Q_{out}:

$$A\frac{dh}{dt} = Q_i - \frac{1}{R}\,H \tag{5}$$

The Transfer Function relatesthe deviation of height, $H'(s)$to $Q'(s)$can be obtained by transforming as shown in equation (5) and rearrange become as shown in equation (6).

$$\frac{H\prime(s)}{Q\prime(s)} = \frac{R}{A\,Rs+1} = \frac{K}{\tau s+1}\text{ ; where}K \triangleq R \text{ and } \tau \triangleq A\,R. \tag{6}$$

The resistance value 0.0092 cm^2 were calculated using experiment in [16] and the bottom tank area equal to 625 cm^2 which complete the transfer function to equation (7)

$$G(s) = \frac{0.0092}{(5.75\,s+1)} \tag{7}$$

2.2. Takagi-sugeno fuzzy logic controller implementation

This project implements zero-order Takagi-Sugeno Fuzzy Logic controller. The form will be described as below where the output will be a singleton spike of a constant value, k to fit our hardware construction. Water tank system has control block diagram as shown in Figure 2.

IF a is X AND b is Y THEN z is k, where k is a constant value.

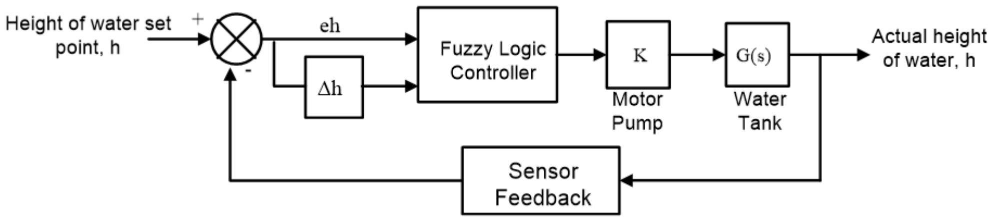
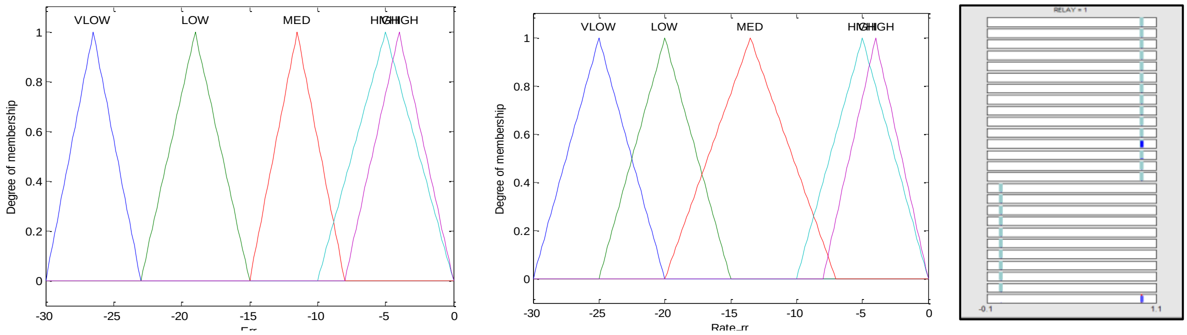


Figure 2. Control block diagram for water tank system

Two input variables were fed into the fuzzy logic controller, error of water height, eh and rate of water height change, Δh whereas one output to motor pump. Membership function for both input are set between [-30 to 0] and output will follow the “on” and “off” concept either “0” or “1” which fit to Takagi-Sugeno interference technique in fuzzy logic controller. The membership functions were tuned with try and error method up until reach the best performance.

Membership function of “error” consists of Very Low (VL), Low (L), Medium (M), High (H) and Very High (VHIGH) with [-30 -26.5 -23], [-23 -19 -15], [-15 -11.5,-8], [-10 -5 0] and [-8 -4 0] in range respectively as shown in Figure 3(a) whereas membership function for “ rate of change” consists of Very Low (VL), Low (L), Medium (M), High (H) and Very High (VHIGH) with [-30 -25 -20], [-25 -20 -15], [-20 -13.5,-7], [-10 -5 0] and [-7 -3.5 0] in range respectively(see Figure 3(b)). The output of the membership function is motor are constant value of zero “off” and one “on”as shown in Figure 3(c).



(a) (b) (c)

Figure 3. Input membership function of (a) ‘Error’ (b) ‘Rate of Change’ and (c) Output either 0 or 1

IF-THEN rule for fuzzy logic controller is constructed as per shown in Table 1 for several water level condition and mapped to the “on” and “off” output. This is where the linguistic definition of a control condition will be defined to align with the objective of the study, maintaining the set water level. Example, the cell (3, 4) in the matrix can be evaluated as: If the rate of change is medium (M) and the distance of error is high (H), then the Pump Motor is OFF.

Table 1. Rule Table of Fuzzy Logic

Entries		Rate or Error ($\frac{dH}{dt}$)				
		VL	L	M	H	VH
Error, ΔH	VL	ON	ON	ON	ON	ON
	L	ON	ON	ON	ON	ON
	M	ON	ON	ON	ON	ON
	H	OFF	OFF	OFF	OFF	OFF
	VH	OFF	OFF	OFF	OFF	OFF

As for the defuzzification methon, the crips output can be obtained with Weighted Average operator.

$$z = \frac{\sum \mu(X)_i \times W_i}{\sum \mu(X)_i} \quad (8)$$

After set up all the Takagi-Sugeno parameter, a MATLAB simulation was done to observe the response of the system based on the developed mathematical equation. Figure 4 shows the simulink diagram for simulation purpose. Since the output of fuzzy logic is either ‘1’ and ‘0’, gain K are used to signify the maximum flow rate of the water DOLPIHN AC pump which is 4731cm^3/sec. However, for the experimental purpose, 5V relay were used to switch on and off the motor pump.

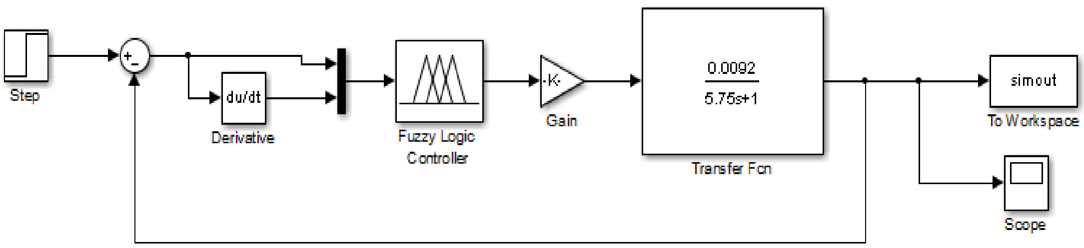
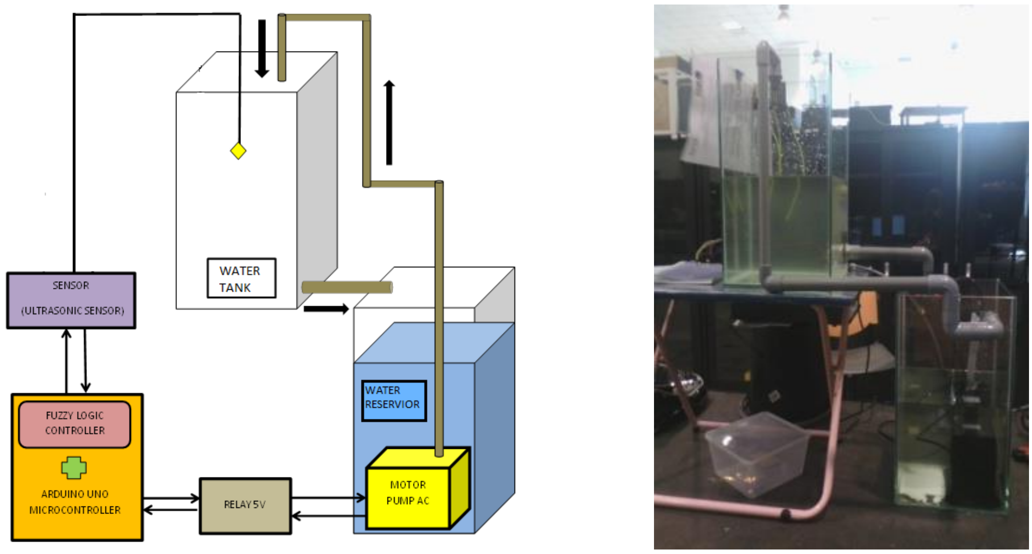


Figure 4. Simulink diagram for fuzzy logic water tank control system

The experimental setup was made to realize developed Takagi-Sugeno Controller for water tank. This section will provide the overview on how the performance of the controller when encounter the real water tank system. Figure 5 illustrate the hardware constructions for the water tank system. The system consists of two water tanks, upper tank as the water level system and another lower tank as water collector only. The 240V DOLPIHN AC pump motor was used to feed the water to upper tank and the height response was controlled by Fuzzy logic controller that being programmed in Arduino Uno (16 MHz clock speed) using C language. Ultrasonic sensor will act as feedback sensor to measure the water tank level. The pump will pump the water continuously until reach the desired height and turn off. During the experiment, the water outlet from upper tank will be shut off. The water level was monitored using serial monitor at the computer.



(a) (b)

Figure 5. (a) Overview of water tank hardware construction and (b) Prototype of the water tank system

3. RESULTS AND ANALYSIS

In Figure 6 show the simulation results for both with and without fuzzy logic controller. Without fuzzy logic controller the water tank system show a good time response but with the amplitude reach maximum of 19.54cm whereas for condition with controller the settling time start at 11 seconds with ripple amplitude of 18.5cm to 20.1cm and the height error reach 0.0678cm. In Figure 7 is Error reduction of water tank system after implementing the fuzzy logic.

Figure 8 show the experimental results for both with and without fuzzy logic controller. Without fuzzy logic controller the water tank system show a settling time at 229 seconds with ripple of 17.72 cm to 18.16 cm whereas with fuzzy logic controller, the settling time start at 59 seconds with ripple between 18.4 cm to 20.05 cm.

Table 2 shows the comparison for both simulation and experimental results. Amplitude ripple happen nearly to all condition except in without fuzzy simulation, thus ripple can be expected in this water tank system range of 17cm to 20 cm. Good settling time in “without fuzzy” simulation results but contradict results shows in experimental test with 229 seconds. The same response happened in “with fuzzy condition” simulation shows settling time of 11 seconds in simulation but experimental produce 59 seconds response.

If compare to literature [14] the experimental response after implementing Takagi-Sugeno fuzzy logic, this study show acceptable performance which lower than 100 seconds and strengthen the statement that Takagi-Sugeno will reduce the computational burden and produce faster response [17].

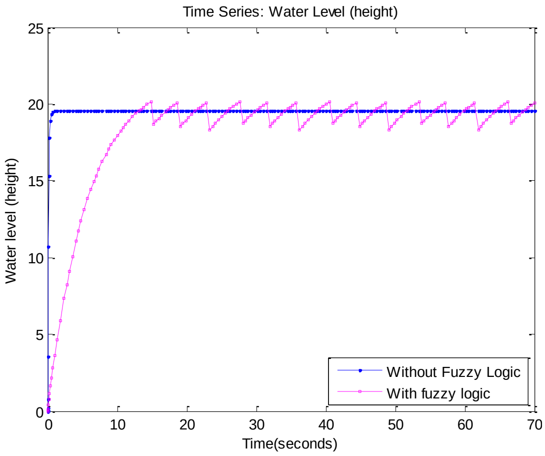


Figure 6. Simulink time response for water tank system

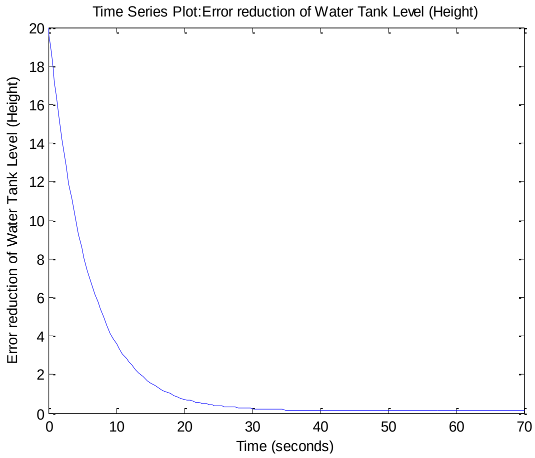
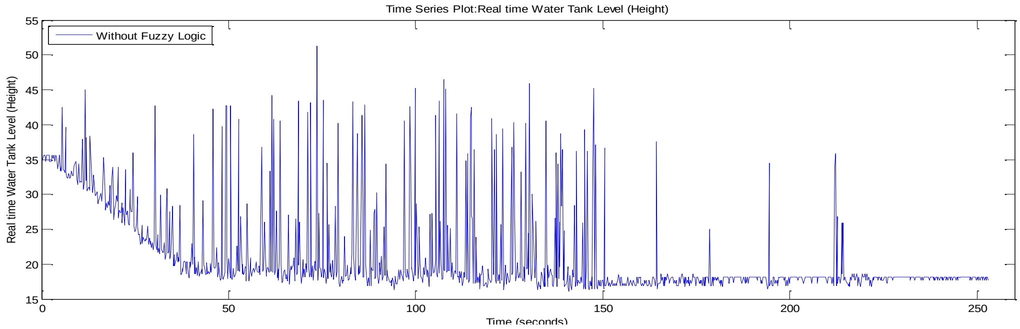
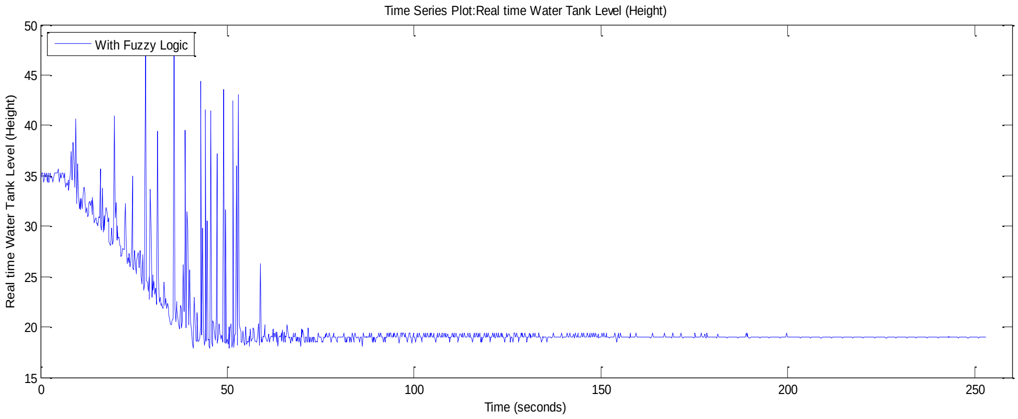


Figure 7. Error reduction of water tank system after implementing the fuzzy logic



(a)



(b)

Figure 8. Experimental results for water tank system; (a) Without Fuzzy logic controller and (b) With Fuzzy logic controller.

Table 2. Performance Comparison of Water Tank System

	Simulation Response		Experimental response	
	Height, cm	Settling Time, s	Height, cm	Settling Time, s
Without Fuzzy	19.54	1	17.27-18.16	229
With Fuzzy Logic	18.5-20	11	18.4-20.05	59

4. CONCLUSION

This paper discussed about the performance of the Takagi-SugenoFuzzly logic controller in water tank system. The mathematical modelling was developed and simulate by using MATLAB/SIMULINK software environment and come out with good results for “without controller condition” but amplitude ripple occur in “with controller”. We develop the water tank based followed the parameter in modelling. Experimental procedure was done in measuring the performance of the prototype of water tank system. The Arduiono microcontroller was used and fuzzy C programming was embedded in the system. The results show acceptable performance in term of amplitude but require more time in reaching a steady state response. However, “with fuzzy logic controller” condition outperform the “without fuzzy logic controller” in practical aspect.

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